The Water Resources 2005 Project (WR2005)

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Abstract

The Water Research Commission has funded a three year study called WR2005 to update and extend a previous surface water resource study (WR90). This WR2005 study has as its focus integrated water resources and an enhanced WRSM2000 model will therefore include new algorithms to describe the groundwater/surface water interface, irrigation, wetlands, mines and streamflow reduction issues such as afforestation, alien vegetation and dryland crops.

This model will be integrated with the SPATSIM system of Professor Denis Hughes to form a new WR2005 system which will make it possible to use database tables, a GIS Viewer and a network builder within WRSM2000 as well as the use of other models.

Meteorological, hydrological, groundwater, water quality and land use data will be collected for the entire country which will be entered into the various models. Calibration and simulation will then be carried out to provide user generated maps and information.

Keywords

Water Resources, WRSM2000, Pitman2005, WR2005, enhancements

1 Introduction

The Water Resources 1990 (WR90) project produced a comprehensive evaluation of the surface water resources of South Africa. This study which was completed in 1994 produced a set of mapbooks containing GIS maps showing various water resource information and appendices consisting of tabulated data and graphs. A new three year study called WR2005 has been commissioned by the Water Research Commission to update and extend the WR90 study. This WR2005 study has as its focus integrated water resources and therefore includes the groundwater/surface water interface, water quality and streamflow reduction issues such as afforestation and alien vegetation. There are seven organisations involved in this project and the nineteen Water Management Areas (WMA's) in South Africa have been divided up between these organisations for the purposes of data collection and analysis based on previous experience in particular catchments in the country.

Huge advances in the computer applications field makes it possible to enhance modeling features. The computer model used to produce a significant part of the information in WR90 (called WRSM90) has already undergone radical improvements. In 2000 a Windows version was released (called WRSM2000) with pull down menus which incorporated rainfall analysis, solved the Y2K problem and made the model far more user friendly. At present, the model is being further enhanced in a two stage process. The various methodologies are the product of many people, acknowledged in this paper.

The mapbooks and appendices produced in the WR90 study will not be re-produced in WR2005 apart from a set of base maps. The emphasis will be in transferring "what if" capability to the user who will be in the more advantageous position of being able to generate his/her own maps by combining any number of coverages and/or information from the database. This is seen as a major step forward over the previous study.

In the sections that follow, the project scope of work including model enhancements, data collection and calibration, training and user support are outlined.

2 WRSM2000 model and improvements

2.1 Stage 1

Numerous workshops were held as part of the WR2005 project as well as for a DWAF initiative on emergency enhancements to the WRSM2000 model to be used for the studies on “Assessment of Water Availability by means of Water Resource Related Models” in the various WMAs. The workshops, held in late 2004 involving most of the experts in the country, allowed all interested and affected parties the opportunity to debate the advantages and disadvantages of the various algorithms/methodologies. Workshops were held on the following water resource issues:

- groundwater
- water quality
- streamflow reductions
- computer issues

Of primary interest was the consideration of algorithms that were previously used, new algorithms that have been developed and recommendations for algorithms that should be included in the new model. The workshops also addressed issues relating to configuration of the model such as database considerations, facility for on-screen network visualisation and creation and the GIS Viewer.

Following these workshops, new algorithms for WRSM2000 were decided on :

- irrigation;
- wetlands;
- groundwater/surface water interface;
- afforestation;
- alien vegetation;
- dryland crops and
- mining.

This is shown schematically in Figure 1.

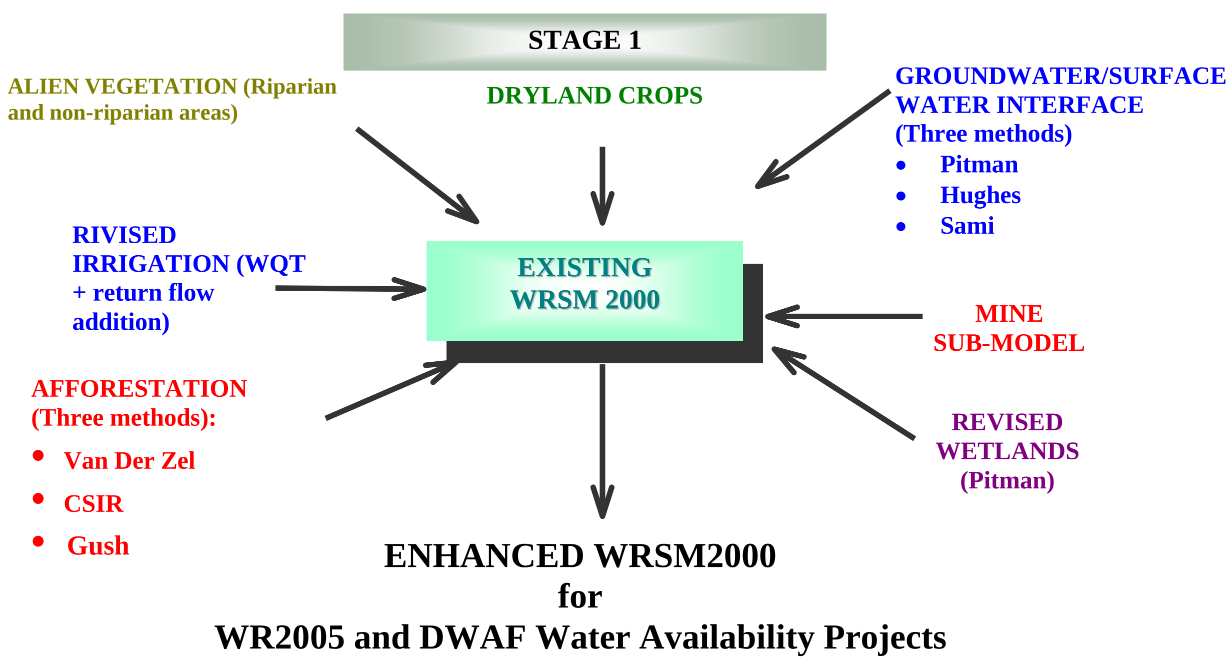


Figure 1

The theory behind the new algorithms is summarised below. The full theory will be available in a separate document as a deliverable from the WR2005 project.

2.1.1 Irrigation

The original irrigation module calculated monthly irrigation demands (in similar fashion to the WQT model) taking into account A-pan evaporation, crop factors, effective rainfall and area under crops. However, return flow was handled in a simplistic way, unlike the WQT model which performs a water balance of the soil moisture underlying the irrigation area. The old irrigation model modelled return flows as proportional to the irrigation supply. This led to the anomaly that the return flow declined as the rainfall increased. While this assumption was adequate for simulating quantity, it was incompatible with salinity modelling. A more constant return flow is expected, since the objective of irrigation is to supplement the rainfall input to match the crop demand, thereby maintaining a relatively constant monthly soil moisture storage.

The irrigation algorithm in the WQT model was used with modifications to the return flow aspect. The area of irrigation is divided into effective and non-effective areas. The irrigation methodology takes account of the natural processes as shown schematically in Figure 2.

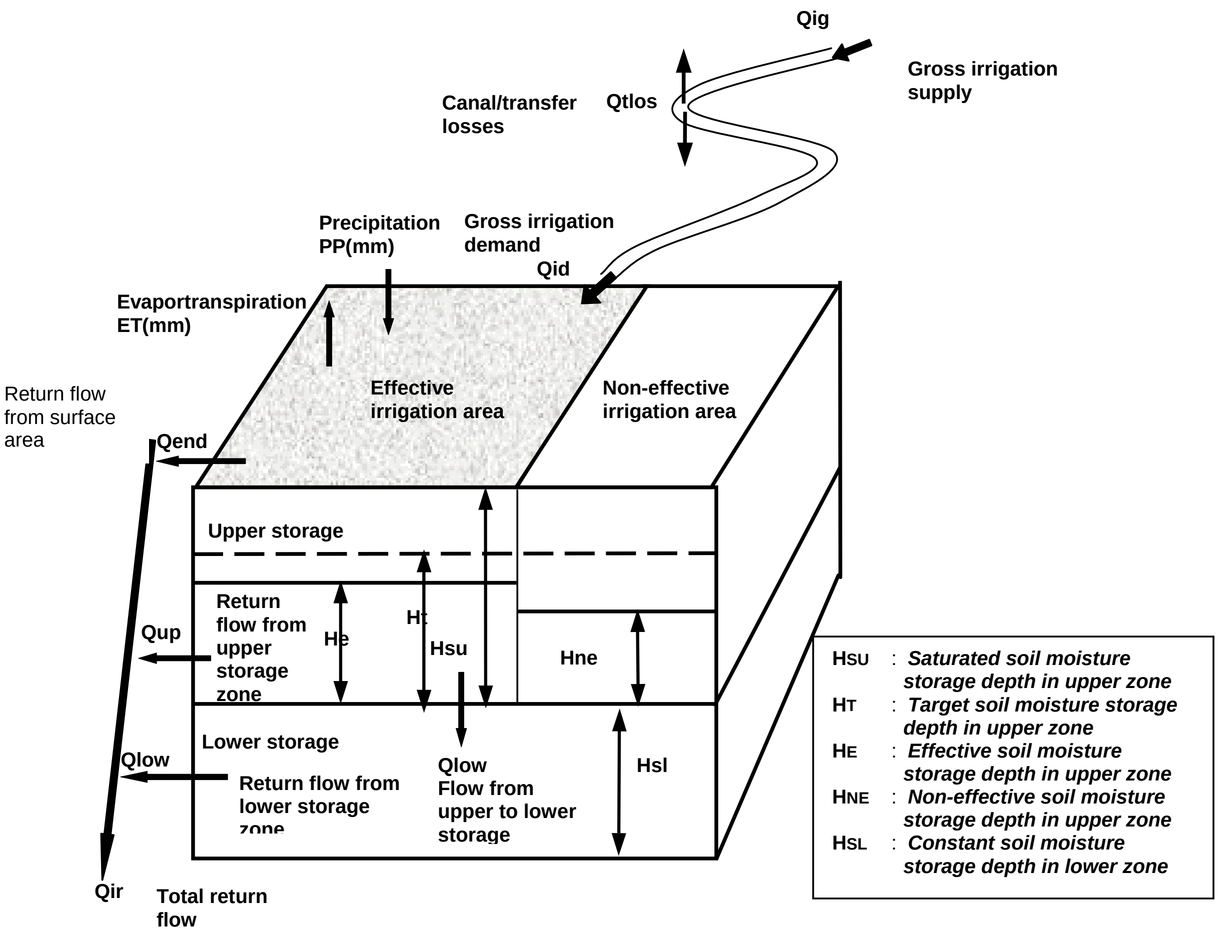


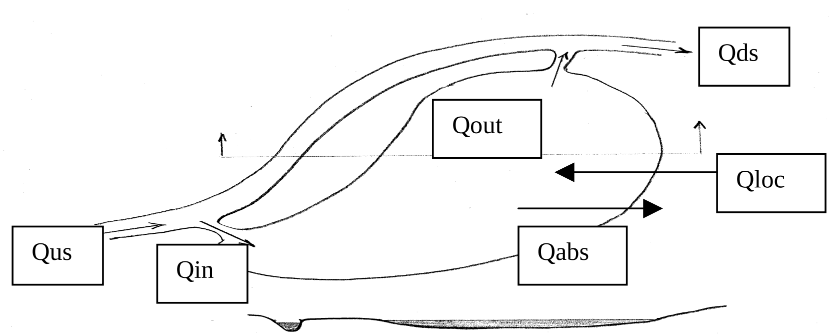
Figure 2

An additional parameter was added to the standard WQT irrigation return flow equation, namely the canal transfer loss. Some of the canal losses are lost from the system as a result of evaporation and some can return to the natural or artificial draining systems through seepage as return flows. This return flow from a canal as a result of seepage was added to the original WQT return flow calculation.

2.1.2 Wetlands

The old wetland model comprises an in-channel storage with a nominal storage volume and surface area, which can be exceeded during high flows. It works like a reservoir where downstream flow takes place only when the (nominal) storage capacity of the wetland is exceeded. This configuration is not realistic for wetlands comprising a defined channel that meanders through a wetland, feeding it with water only when the river channel capacity is exceeded. The flow of water between channel and wetland can be in the form of overbank spillage or via channels, or a combination of both. Examples of such wetlands are to be found in the Kafue River (Zambia) and the Pongolo River (RSA). The new wetland model is designed to simulate a wetland that is either off-channel or in-channel. It can also be employed to simulate the effect of a man-made off-channel storage dam for water supply.

The new wetland model is depicted in Figure 3. Showing a single link from river channel to wetland and another single link from wetland back into the channel facilitates visualization of the model. A real wetland has many links, where water can flow from channel to wetland and vice versa, depending on water levels. As is the case for the old model, the wetland has a nominal storage capacity and surface area, which can be exceeded. In the new model, however, the nominal values refer to the wetland storage (and associated area) below which there is no linkage to the river channel. Flow from wetland to channel is governed by the storage state of the wetland and is proportional to the storage volume over and above the nominal capacity. Flow from channel to wetland occurs when channel flow is above a prescribed threshold. The surplus flow is then apportioned between river channel and wetland link. If the model is to be used to simulate off-channel storage an upper limit can be set for the flow in the channel to wetland link, equivalent to the diversion capacity. The model also caters for local runoff entering directly into the wetland.



Qloc	=	Local inflow directly into wetland
Qus	=	Flow in river channel upstream of wetland
Qds	=	Flow in river channel downstream of wetland
Qin	=	Flow into wetland from river channel
Qout	=	Flow into river channel from wetland
Qabs	=	Rate of abstraction from wetland/off-channel storage

Figure 3

2.1.3 Groundwater/surface water interface

The existing WRSM2000 is essentially a surface water model and deals with groundwater simplistically through it's calibration parameters – specifically the maximum groundwater flow (GW) and groundwater lag (GL) parameters. Two additional methods are to be implemented which deal far more extensively with groundwater, namely the methodology of Professor Denis Hughes (Hughes, 2004) and Mr Karim Sami. The methodology of Sami is tied to the Water Resources Yield Model (WRYM) and in particular stochastic analysis and is therefore to be used for the DWAF Water Water Availability studies whereas the Hughes methodology is to be used for the WR2005 project. Both models use the same recharge function, based on a relationship with soil moisture storage similar to the function controlled by FT and POW in the original Pitman model. The Sami approach estimates a ground water storage level and outflows based on assumed head differences between the ground water and channel. The Hughes approach uses a simple representation of sub-surface ground water storage geometry and simulates variations in slope (both positive and negative) toward the channel. Monthly variations in ground water contribution to streamflow are based on these slopes, the geometry and the transmissivity, while this outflow process can also be affected by riparian evapotranspiration losses. When the ground water slope is negative it is possible to simulate channel transmission losses from flow generated either within the specific sub-catchment, or from upstream flows. Although the Hughes and Sami have significant differences, they give similar results. The following Figure 4 shows a very simplistic schematic for the Hughes approach.

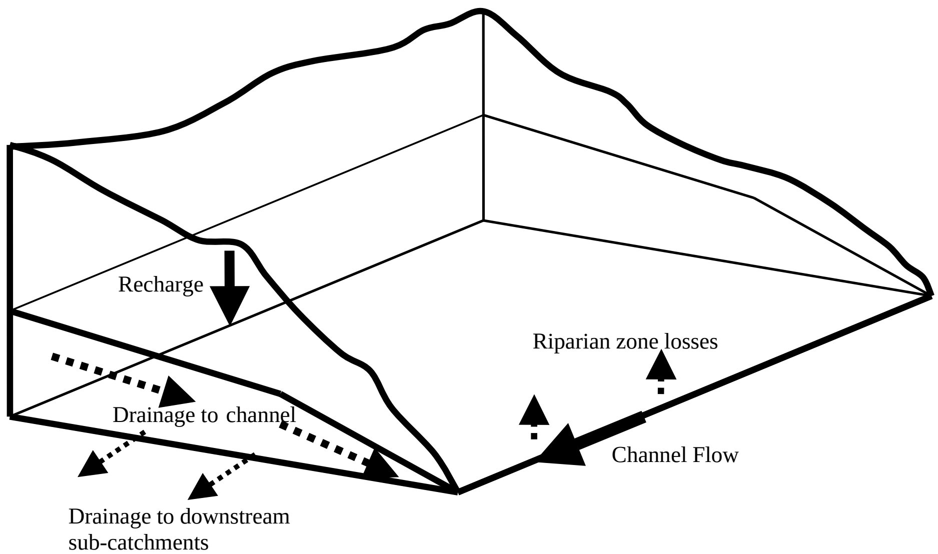


Figure 4

The "WRSM2000 screen shot" in Figure 5 shows the input screen for groundwater with the Hughes method chosen.

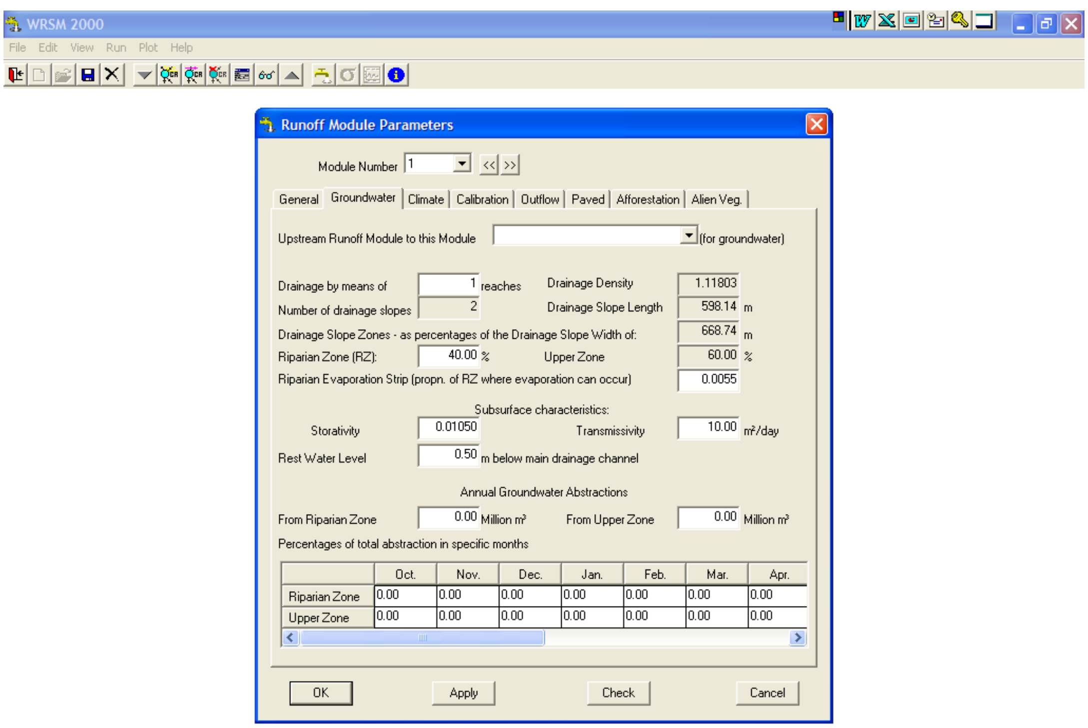


Figure 5

One of the major impacts of the new groundwater/surface water interface methodology is that there are five new calibration parameters with the Hughes method and three with the Sami method.

The "WRSM2000 screen shot" in Figure 6 shows the new input calibration screen for the runoff sub-model. This screen shows that the Hughes method has been chosen which results in 13 calibration parameters being active and three (for the original Pitman method) being inactive.

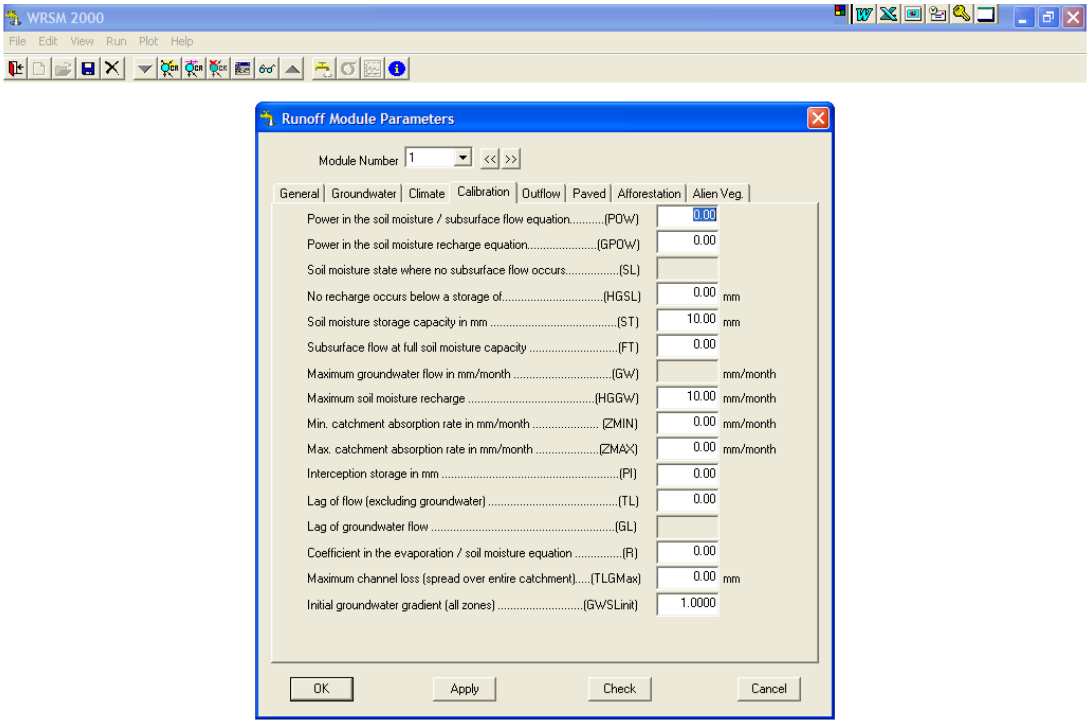


Figure 6

2.1.4 Afforestation

Two methods already exist in WRSM2000. The first, the Van Der Zel method, is considered outdated. It has been retained in the model merely for purposes of comparison with other methods and to duplicate previous simulations. The second method, the CSIR method, has previously been included in a version of WRSM2000 not yet officially released.. Afforestation can be classed into one of three groups, namely : pines, eucalypts and wattle. The methodology was developed by Dr David Scott and takes into account % area, rotation length and % optimal growth for each of the three types. The overall area can vary with time. A third method is based on Gush tables with certain algorithms developed by Dr Bill Pitman to interface with Gush data. Pitman has developed global regression constants to predict the relationship among various model parameter adjustments and % MAR reduction and % low flow reduction which have been tested on eight diverse quaternary catchments.

The parameters adjusted to account for replacement of natural veld with forest plantations are as follows:

PI – the interception storage in mm;
FF – the factor by which potential evapotranspiration is increased (analogous to crop factor);
SL – the soil moisture storage below which runoff ceases and
ST – the maximum soil moisture capacity.

2.1.5 Alien vegetation

Two types of alien vegetation are to be dealt with, namely riparian and non-riparian. Non-riparian vegetation already exists in an unreleased version of the model. For alien vegetation the following three types are used for classification : tall trees, medium tress and tall shrubs. The methodology was developed by Dr David le Maittre and takes account of % area, age and % optimal growth for each of the three types. The overall area can vary with time. Non-riparian alien vegetation is treated in a similar manner to afforestation. Since both groundwater sub-models allow for evapotranspiration loss from a riparian zone, alien vegetation in this zone can be accommodated here.

2.1.6 Dryland crops

Information from other sources will be used to provide information on the hydrological impacts of dryland crops. This information can be used in similar fashion to that for afforestation, namely the adjustment of certain model parameters to achieve required reductions in MAR and low flow. The dryland crop with greatest impact on runoff is sugar cane, however, other crops can be treated in similar fashion once their impacts have been established.

2.1.7 Mines

A mine module was deemed necessary for the Olifants Water Management Area, particularly as a result of the extensive coal mining activity in the Upper Olifants where the water quality has deteriorated so much that it is unsuitable for certain purposes. This led to development of a mine module that dealt with both quantity and quality aspects and was incorporated into WQS, a sulphate version of the Water Quality Model (WQT). For WRSM2000, only the quantity aspects are to be incorporated.

A typical mining operation can consist of underground mining, opencast mining, a coal washing plant, discard and slurry dumps, pollution control dams and a coal beneficiation plant. A generic layout is shown in Figure 7.

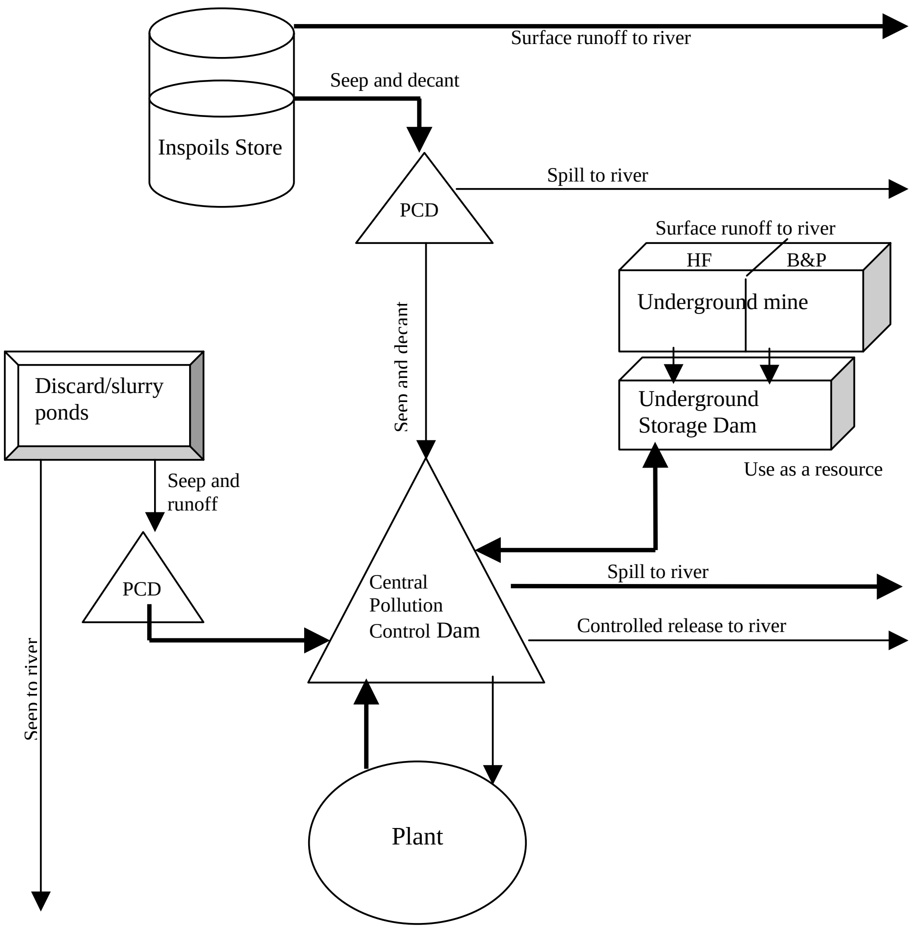


Figure 7

The quantity aspects for underground mining, opencast mining, a coal washing plant, discard and slurry dumps, pollution control dams and a beneficiation plant have therefore been included in the WRSM2000 model.

2.2 Stage 2

The enhanced version of WRSM2000 will be integrated with the SPATSIM system of Professor Denis Hughes to form a new WR2005 system, which will contain the following four models:

- Pitman2005 (a further enhanced form of WRSM2000 but containing the identical algorithms);
- Simplified mass balance water quality model;
- Desktop Reserve model and
- Stress response model;

This WR2005/SPATSIM system will therefore be a framework which encompasses all models, all input and output requirements in the database as well as tools to work with such as the GIS Viewer and network builder.

This is shown schematically in Figure 8.

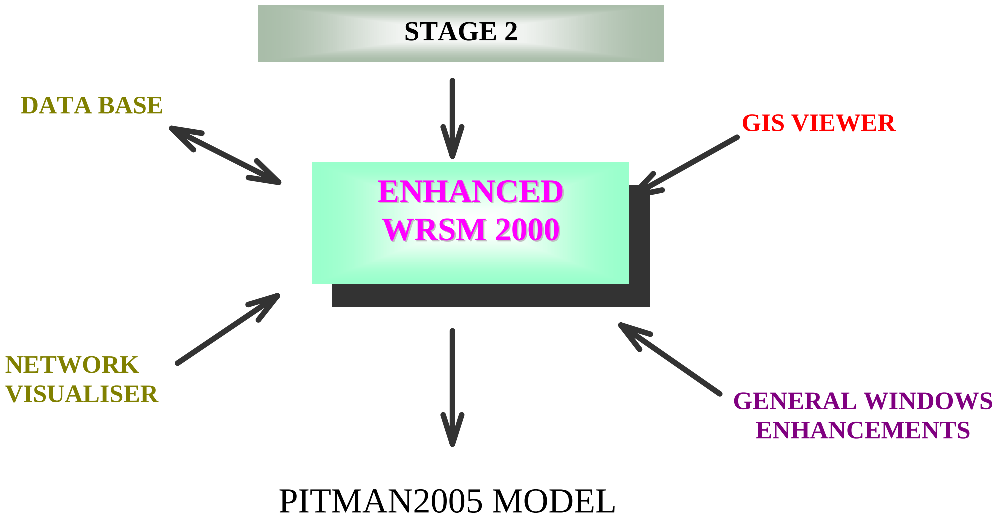


Figure 8

There will be two levels of WR2005 system, namely a basic version just allowing access to pre-computed data and a more enhanced version which includes the models and allows users to analyse WR2005 information as well as generate their own information on a catchment. These WR2005 systems will allow textfiles or database tables for input and output of data. Database tables will be the preferred method for the future. The database is only for South Africa, Lesotho and Swaziland but there is a possible future expansion to SADC countries for which there has always been a demand for WRSM2000 and previous versions of Pitman model. The "textfile" version is currently necessary for other countries.

Spatial data will also be stored in the database for viewing via a GIS Viewer. This will enable users to generate and plot their own GIS maps. The emphasis will therefore on the user generating required information rather than the WR90 approach where all information was disseminated in hard copy format together with a CD for time series data. It is envisaged that users will be able to download data from the Internet.

3 Data Collection and Simulation

As a parallel activity to programming of the WR2005 system, a data collection phase is underway to collect all meteorological, hydrological, water quality, water use and land use data over the entire country. The first step was to collect the rainfall data. It was decided to accept the WR90 patched rainfall and to append the latter part of the record up to September 2005 using the DWAF Rainfall Information Management System (IMS). Various tools have been developed to aid in the selection and patching of rainfall stations including a procedural document and checklist. The WRSM90 networks that are still available from the WR90 study will be used together with others that will have to be re-generated. These networks will be brought into line with the Pitman2005 model input requirements and brought up to date using the extended patched rainfall time series, water use data such as abstractions and return flows and observed flows, plus land use data on paved areas, irrigation, afforestation, alien vegetation and dryland crops. Data on reservoirs and wetlands will also be updated.

Regarding groundwater, use will be made of the DWAF GRA2 study output. This will be mainly in the form of GIS maps for sub-zone grouping of quaternary catchments with similar hydrogeological characteristics, groundwater yield, groundwater abstractions, groundwater levels, average groundwater storage, average annual recharge and average transmissivity. A groundwater balance is also available in spreadsheet form. The Pitman2005 model will produce the groundwater storage and it's contribution to time series of simulated monthly flow.

Once the Pitman2005 model is complete, calibration and simulation will be carried out on the integrated water resource systems.
As a separate activity, Dr Chris Herold has developed software to analyse water quality data for the entire country. This task will also require extensive data collection and analysis. These analyses will include TDS, pH, orthophosphate, total ammonia, sulphate, nitrogen and fluoride. Cumulative present day median and 95 percentile concentrations will be provided for each key water quality variable for each quaternary catchment where sufficient representative data is available.

Tables of SA Water Quality guidelines for domestic, irrigation and the natural environment will be included in the database for comparison with quaternary quality data to produce fitness for use information at quaternary outlets. Water quality data will be collected for major effluent dischargers to each quaternary catchment.

A simplified salt balance model has been developed and will be calibrated for selected key catchments using observed data over the last 30 years. This will enable users to rapidly evaluate the likely salinity consequences at a quaternary catchment scale of the chosen water resources options.

Estimates of the Ecological Reserve will be made using the monthly Desktop Reserve model (Hughes and Hannart, 2003) or the daily time-step IFR model (Hughes et al., 1997) to generate time series data. The SPATSIM database will contain all the default parameters for running the Desktop Reserve model, as well as default categories for the Present Ecological State (PES), where this is available. For more detailed assessments, software to facilitate the application of the Flow Stressor Response methods (O'Keeffe et al., 2002) will also be made available as part of SPATSIM.

4 Training

Previously disadvantaged individuals are playing a role in most aspects of the study and are receiving on-the-job training where required. Towards the end of the project in 2007, courses will be organised in the major centres in the country on the use of WR2005. Presentations will be made at certain universities and technikons.

5 Deliverables

The product of this study will be the WR2005 system complete with enhanced models, database containing information on integrated water resources for the entire country and input and output required for the various models. Most of the data will be stored on a quaternary catchment resolution based on a monthly time step. Users will be able to access GIS layers using the DWAF GIS Viewer. This will be available on a CD. Hard copy deliverables will be WR2005 and Pitman2005 user manuals as well as theory and Pitman2005 code documents. The WR2005 user manual will contain some base GIS maps. It is envisaged that the products of this study will greatly facilitate the analysis of integrated water resources across the country for a wider range of users than was the case with WR90.

6 User Support

There will be a user support system comprising a small group of individuals to assist users for the first year. Further support beyond that is to be discussed and organised at a later stage.

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Dr Bill Pitman (wetlands, afforestation)
Professor Denis Hughes (groundwater, Ecological Reserve, SPATSIM)
Dr Chris Herold (water quality, irrigation)
Mr Trevor Coleman (mining)
Mr Pieter Van Rooyen (mining)
Mr Karim Sami (groundwater)
Dr David le Maittre (alien vegetation)
Dr David Scott (afforestation)
Mr Mark Gush (afforestation)

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